The effect of mesoscale eddies on air-sea interactions

— a view from the ocean

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22 September 2019

Ocean mesoscale eddies

- They are the "weather" of the ocean, with horizontal scales of ~100km and timescales of ~1month;
- They typically exhibit different properties to their surroundings, allowing them to transport properties such as heat, salt and carbon around the ocean;
- The largest scale eddies emerge from instabilities of strongly horizontally sheared motions, particularly in boundary currents. These eddies often take the form of well defined rings extending to great depth. At slightly smaller scales, eddies are generated by baroclinic instability.

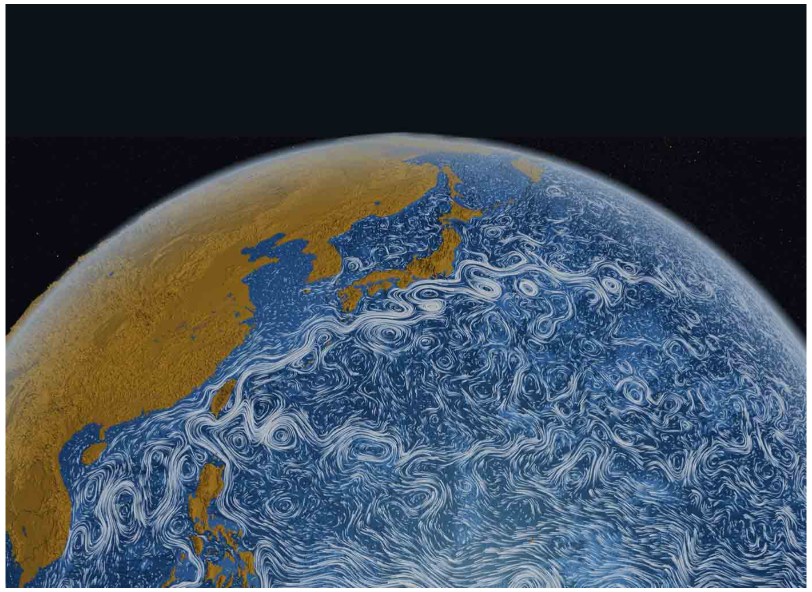


Fig1: NASA visualization of ocean eddies

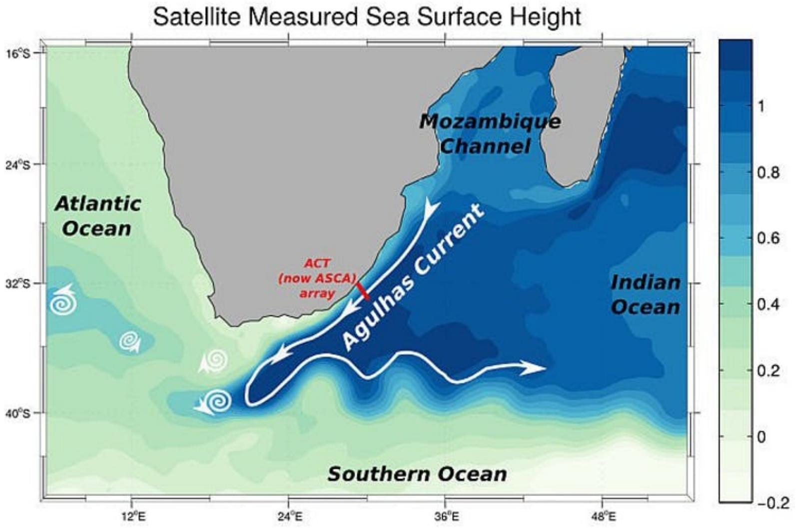


Fig2: Generation of Agulhas rings

Air-sea interaction over ocean eddies

- At large scales, intensified winds cool the ocean surface through evaporation, as well as increasing the entrainment of upper-thermocline waters into the mixed layer.

- So the correlation between wind speed and SST is often negative, which means the atmosphere is driving an ocean response.

- However, recent observations show a positive correlation over ocean mesoscale features, which is suggestive of the ocean forcing the atmosphere, mainly through heat fluxes out of the ocean.

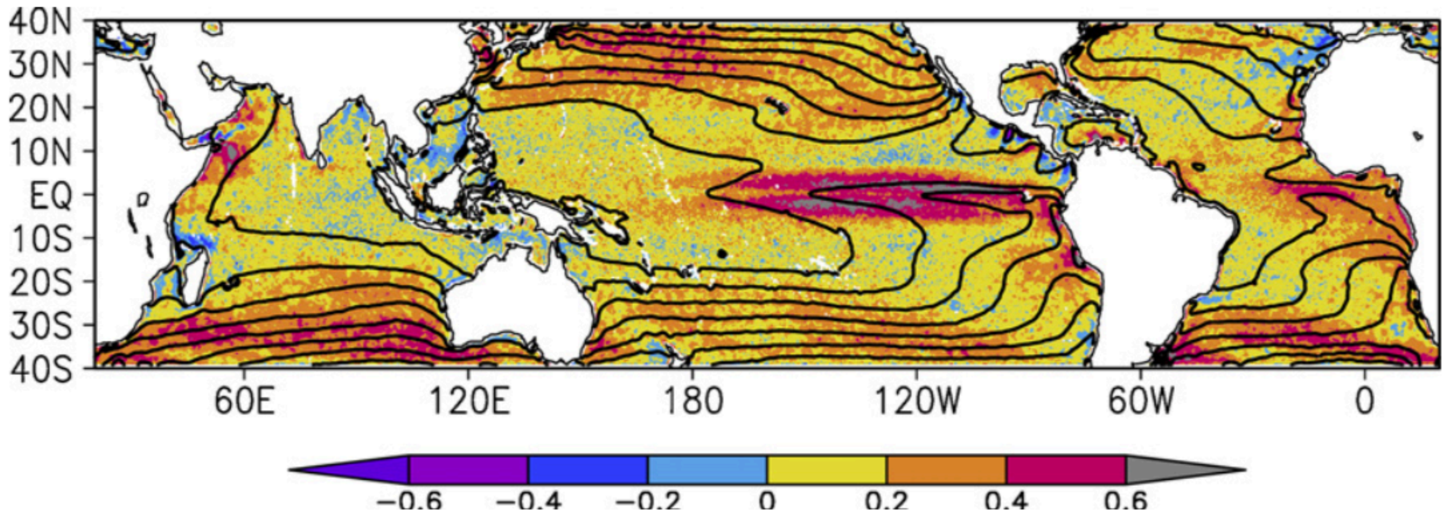


Fig3:A map of the correlation between SST and neutral 10m wind speed at the mesoscale.
(from R.J. Small et al. 2008)

Air-sea interaction over ocean eddies (an emphasis on the atmosphere)

- There are several reasons why the atmosphere is affected by ocean eddies.
- Example 1: as air is blowing across an SST gradient, an air-sea temperature/humidity difference is generated. This leads to changes in near-surface stability.

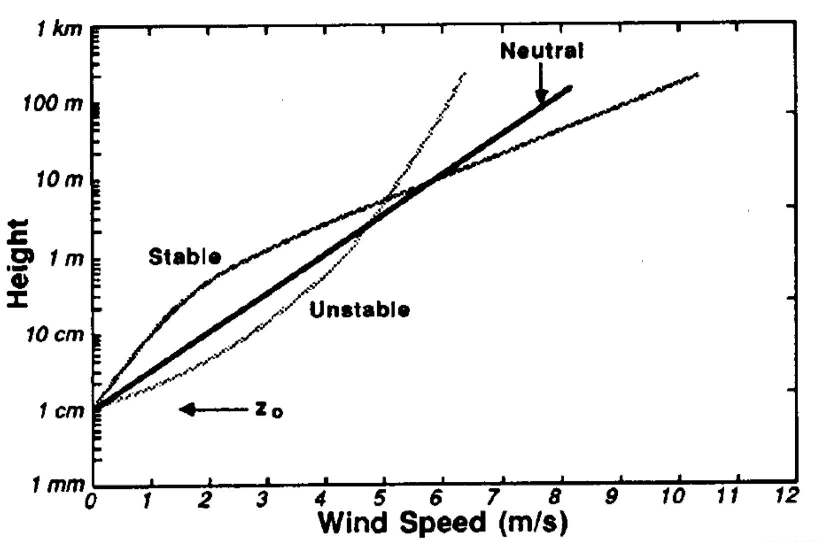


Fig4: Typical wind speed profiles vs. static stability in the surface layer.
(from R.B. Stull 1988)

Vertical gradients of wind speed:
Stable: increase
Unstable: decrease

- Example 2: The atmospheric pressure also changes, leading to a spatial pressure gradient which can drive secondary circulations.

Air-sea interaction over ocean eddies (an emphasis on the ocean)

- The viewpoint from ocean response:

  1) Surface currents of ocean eddies will impact the relative motion of the air and ocean, acting to change the surface stress, thus affecting the atmosphere as well as feeding back onto the ocean.

  2) Ocean Ekman layer dynamics is also modified by eddying currents, even with an invariable wind stress.

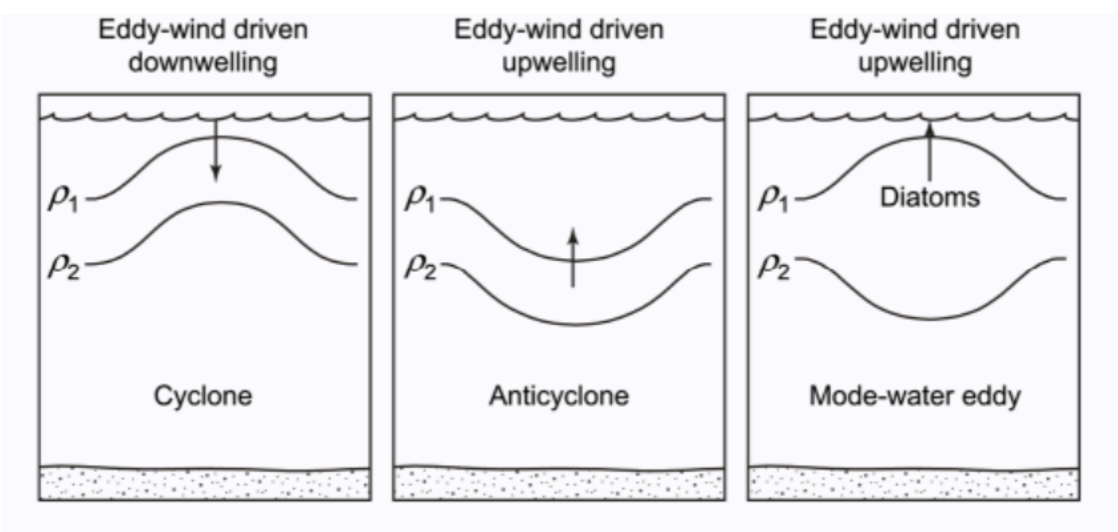


Fig5: Isopycnal displacements associated with three types of eddies. Two density surfaces are depicted seasonal and main thermoclines respectively. (from D.J. McGillicuddy et al 2007)

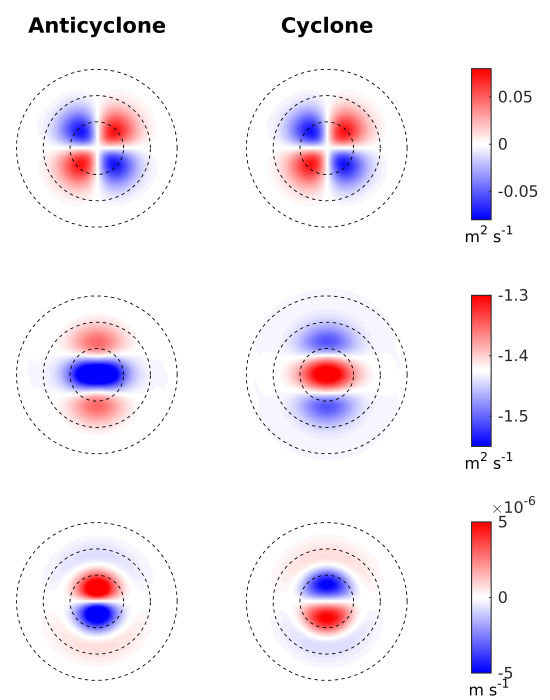


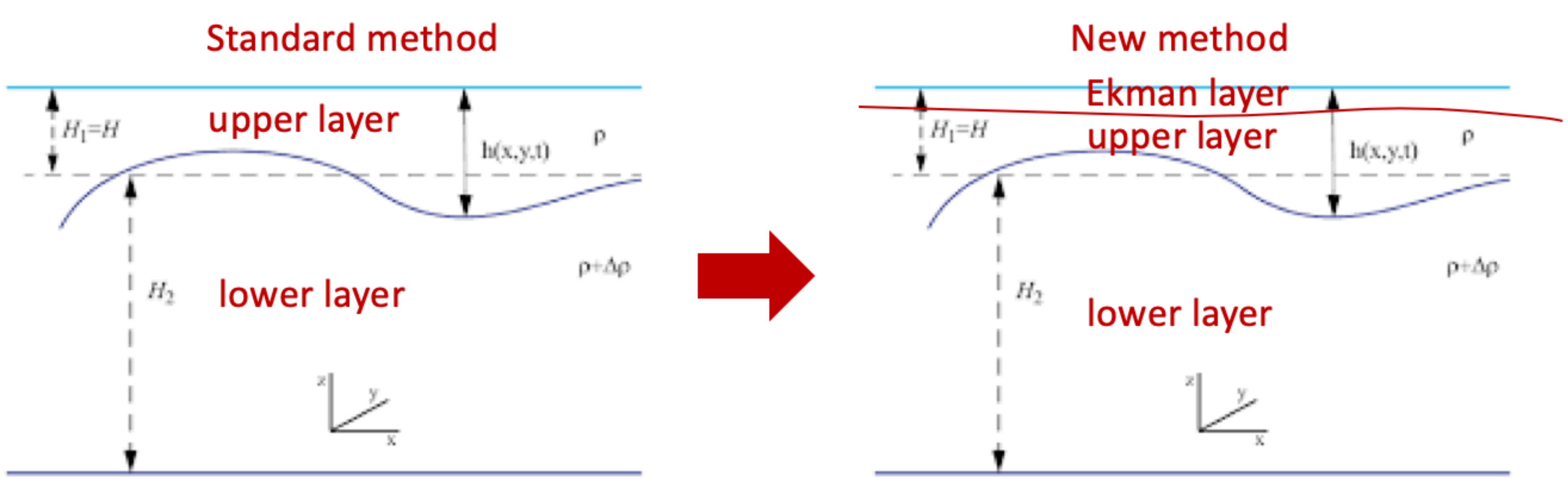
Fig6: Eddy-dependent zonal transport, meridional transport and Ekman pumping velocities.

Flow-dependent Ekman dynamics

- The Ekman equation in our model

$$\frac{\partial \boldsymbol{u}_{Ek}}{\partial t} + (\boldsymbol{u}_{Ek} \cdot \nabla)\boldsymbol{u}_0 + (\boldsymbol{u}_0 \cdot \nabla)\boldsymbol{u}_{Ek} + (\boldsymbol{u}_{Ek} \cdot \nabla)\boldsymbol{u}_{Ek} + f\hat{z}\times\boldsymbol{u}_{Ek} = \frac{\partial \boldsymbol{\tau}}{\partial z} - A_h \nabla^4 \boldsymbol{u}_{Ek}$$

- Comparison between two regimes:
  1) Standard: wind stress is applied as a body force in the upper-layer momentum equation;
  2) New: use an explicit Ekman layer to force the upper-layer mass equation.



Flow-dependent nonlinear Ekman dynamics

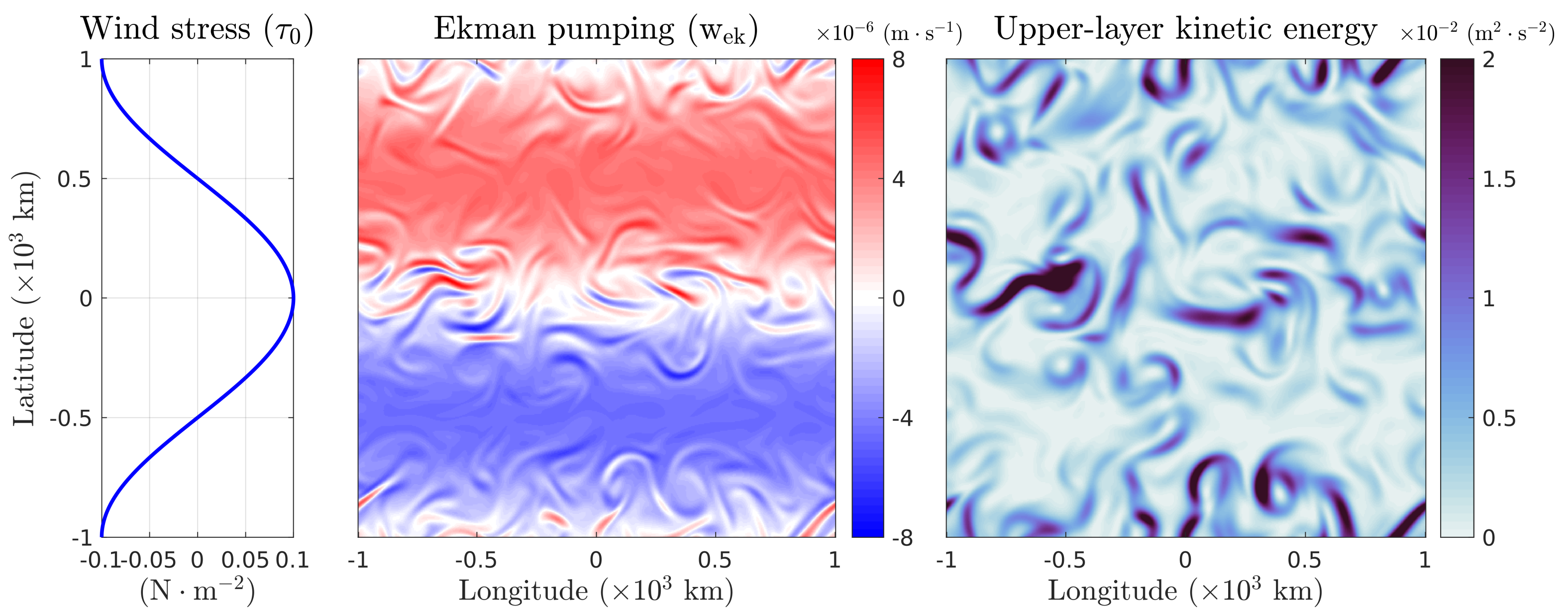


Fig7: The two-layer shallow water model response to a baroclinically unstable jet (with the new method).

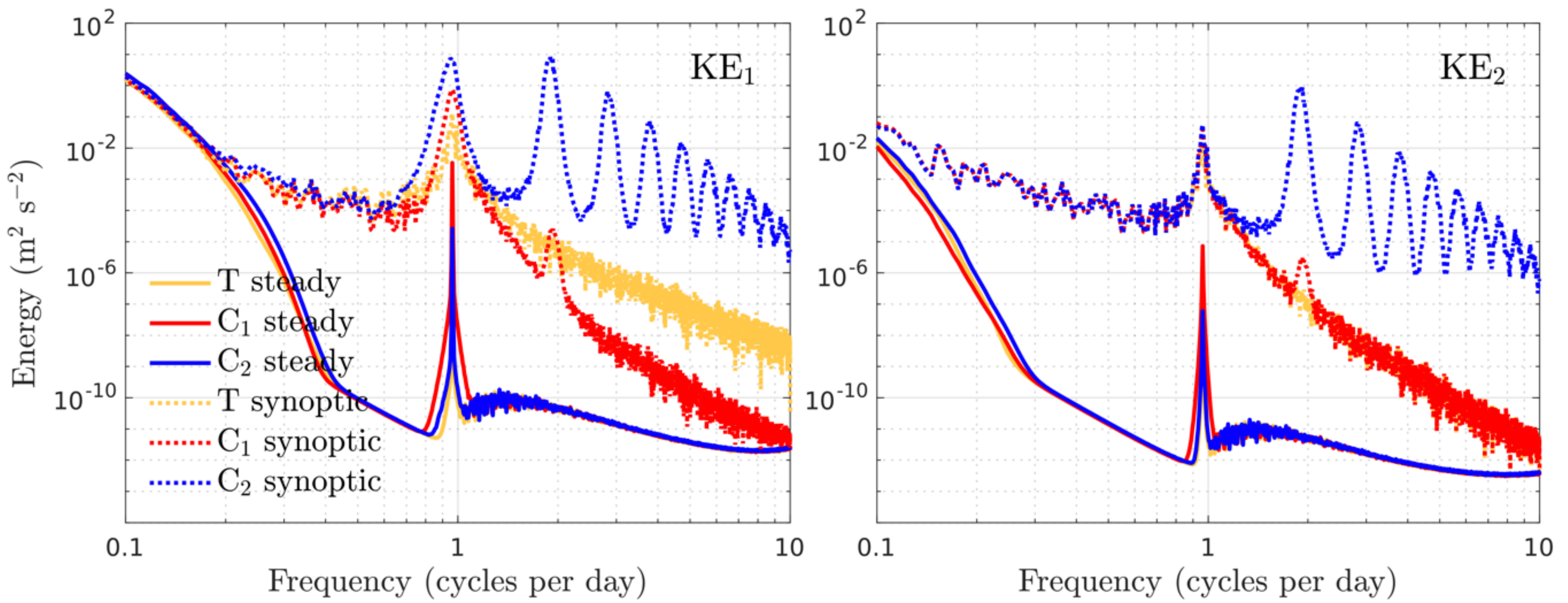


Fig8: The frequency spectra of upper and lower layer kinetic energy (T is the standard two-layer model; C1 and C2 are the new coupled models).

EUREC⁴A and ocean eddies

- Very few observations are available to quantify the role of ocean eddies in the transport of water properties and in air-sea interactions, especially in the tropics.

- In particular, intense warm eddies converge in the western tropical Atlantic, offshore of Barbados. They carry freshwater from the Amazon river, which results in intensification of storms.

- Moreover, a synoptical study from different research vessels measuring different mesoscale eddies across the experimental area will provide new information on water-mass characteristics advected by the regional eddies. Vertical profiling of the water column will be measured as well.

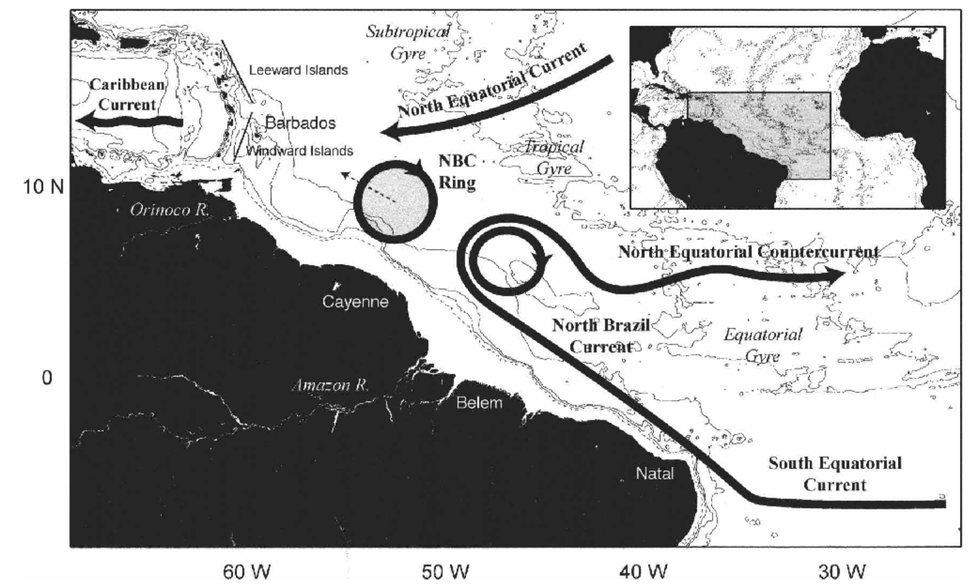


Fig9: Circulation in the western tropical Atlantic Ocean (from D.M Fratantoni et al. 2006).

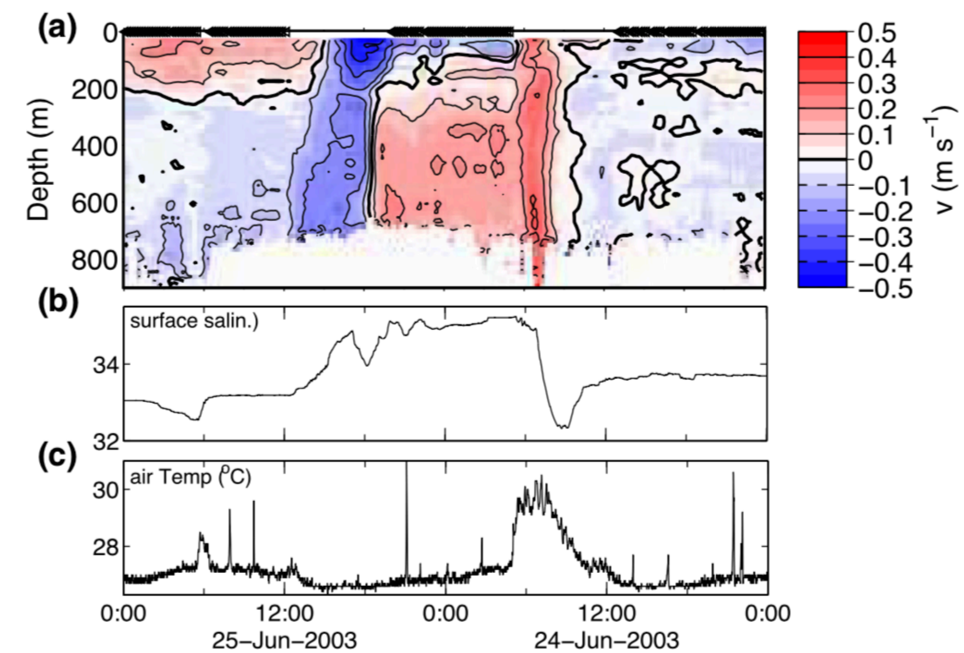


Fig10:RV SONNE ship survey through an anticyclonic eddy west of Barbados.
(a)Meridional current ; (b)Sea surface salinity; (c) Air temperature.

Thanks for your attention.